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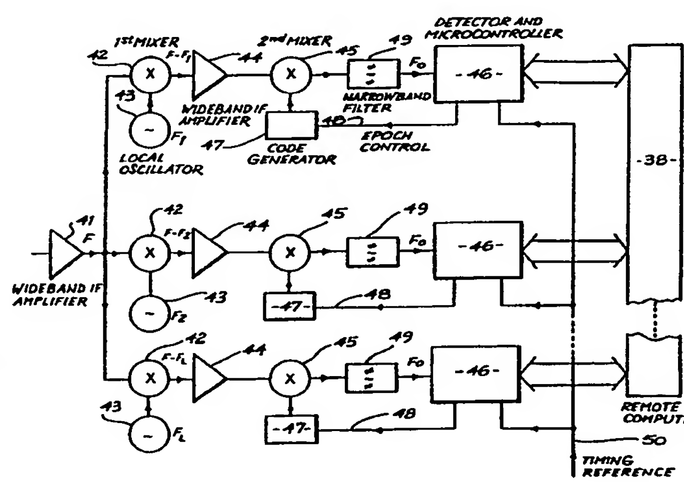
(54) Title: IMPROVEMENTS IN A SPREAD-SPECTRUM MULTIPLEXED TRANSMISSION SYSTEM

(57) Abstract

A spread-spectrum transmission system wherein one or more spread-spectrum signals occupy the same frequency band as a group of substantially equally spaced conventional communications channels, the spectral line spacing of the spread-spectrum signals being selected to correspond to the inter-channel spacing of the group of communications channels such that the spectral components of the spread-spectrum signals fall within the inter-channel guard bands of the communications channels. If more than one spread-spectrum channel is used, they are frequency division multiplexed by offsetting the centre or carrier frequencies of the spread-spectrum signals by a fraction of the spectral-line spacing of the signals. The signals are generated by modulating a carrier with a pseudo-noise (PN) code signal. Demultiplexing is achieved by generating the same PN code in a code generator (47) and mixing the PN code with the received signal in a mixer (45). The epoch of the code generated by the generator (47) is then advanced or retarded in response to an epoch control signal (48) generated by a controller (46). The mixed signal is passed through a narrowband filter (49) to select the baseband signal which is then fed to the controller (46) to enable the generation of the epoch control signal (48). When applied to a vehicle tracking system, the relationship between the epoch of the noise code and the reference signal (50) is used to indicate the relative propagation delay, when correlation with the received signal is achieved. The delay information, when combined with information from receivers at other locations, can be used to calculate transmitter position.



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IMPROVEMENTS IN A SPREAD-SPECTRUM MULTIPLEXED TRANSMISSION SYSTEM

BACKGROUND OF THE INVENTION

The present invention relates generally to improvements in spread-spectrum transmission systems and in a preferred embodiment the invention is applied to a vehicle location and tracking system.

A number of information bearing channels can share the same medium and approximately the same frequency band and yet be separated at the receiving end with satisfactory interchannel isolation if suitable pseudo-noise (PN) codes are used asynchronously to direct-sequence modulate the channel carriers at a high rate relative to the data rate. This has the effect of spreading the spectrum of the transmitted energy.

At the receiver, the information in each channel is extracted by cross-correlating the incoming composite stream with the code associated with the desired channel. When the clock rates and the epochs of the in-coming and locally-generated codes match, the spread-spectrum energy is collapsed to the relatively narrow, data bandwidth for that channel whilst all the other channel spectra remain spread.

This method enables a particular medium (eg a coaxial-cable transmission line) to carry a large number of channels, separation being achieved at the receiving end by code-division multiple access (CDMA). The performance of the scheme in terms of signal- to-noise ratio depends on the relative orthogonality of the codes; that is, on their cross-correlation properties. A unique feature is the smooth degradation of signal-to-noise ratio as more users come into the system compared to the sudden loss of performance which occurs in a conventional frequency division multiple access (FDMA) system once the channel capacity is exceeded.

The capability of a spread-spectrum channel to reject

interference from other signals in other channels and from noise is called the process gain. Mathematically, process gain is given as:

$$G_p = 10 \log_{10} B/b \quad \text{(dB)} \qquad \ldots (1)$$

where B = bandwidth of spread-spectrum signal
b = data or information bandwidth

and it is assumed that the spectral line spacing of the PN codes is small enough for the spectra to be considered continuous.

Consider now the case of one transmitter, one receiver and no data. According to equation (1) the process gain is infinite because $b \rightarrow 0$. The zero-data example might be a ranging system where it is necessary only to locate the code epoch and, knowing the propagation delay, the range to the transmitter may be calculated; range ambiguity can be avoided by making the code repetition period much greater than the propagation delay. In practice the process gain can be very large, but not infinite, and is limited mainly by the extent of the loss of coherence of the carrier at the receiver relative to the receiver local oscillator. If the 'coherence time' of the received carrier is τ then $b \sim \tau^{-1}$ and process gain can be increased only by spreading the spectrum of the transmitted signal still further. This can be done by increasing the chip-rate (code clock rate) of the PN code up to a limit set by the electronics or by the ability of the transmission medium to support the spread-spectrum bandwidth.

Referring to Fig. 1 it may be seen that in a spread-spectrum location and tracking system, the vehicle 10 or object to be located emits a continual direct sequence spread-spectrum radio signal 11. This transmission is

received at a number of well-spaced receiving stations 12 in the coverage area and the differences in the times of arrival of the signals at these receivers are measured. Inverse hyperbolic navigation techniques then may be used to compute the position of the transmitter at the central computer 13 which then sends this information to an operator terminal.

Direct sequence spread-spectrum modulation is employed for a number of reasons, one of which is to minimise multi-path effects. Also, since for location and tracking purposes there is no data transmission requirement, there would appear to be potential for very high process gain. Unfortunately the process gain is severely limited in practice. Firstly transmissions from a vehicle moving in an urban, or suburban, area experience Rayleigh scattering and Doppler frequency-shift. As a result, at each receiving site 12 the received signal spectrum is bandlimited to within $\pm \Delta f$ of the centre frequency where $\Delta f = f_o v/c$ is the maximum Doppler frequency-shift for a vehicle with speed v transmitting on a frequency f_o (c is the speed of radio propagation). The coherence time of the carrier depends roughly inversely on the width of the frequency-modulation spectrum so that this scattering sets a lower limit to b, the post-correlation bandwidth. Secondly, the radio-frequency spread-spectrum bandwidth cannot be made arbitrarily wide because of limitations on the coherence bandwidth caused by different fading in different parts of the spectrum.

A rough estimate of the available process gain using urban mobile transmitters may be obtained from published data. For a centre frequency of about 450 MHz the minimum coherence time is about 5 ms and the coherence bandwidth is around 1 MHz giving an available process gain of approximately 37 dB. This figure gives a measure of the

level of signal enhancement, over broadband spectrally-continuous noise and interference, achievable by receiver processing.

For a spread-spectrum multi-vehicle location and tracking system in which M transmitters are operating simultaneously, each transmitter to be located and tracked has (M-1) interferers. If CDMA is used, the cross-correlation properties of the codes of the wanted and unwanted signals will determine the extent of the interference. In the commonly-used binary Gold code family, the cross-correlation between any pair of codes generated using n-bit shift registers is bounded by

$$|\Theta(r)| \leqslant 2^{(n+1)/2} + 1 \qquad \text{(n odd)}$$
$$|\Theta(r)| \leqslant 2^{(n+2)/2} - 1 \qquad \text{(n even)}$$

Since these sequences are of maximal length, the number of bits in the code is:

$$N = 2^n - 1$$

and for $n \gg 1$ the ratio of the auto-correlation peak to the maximum cross-correlation bound is

$$R \sim 2^{(n-1)/2} \qquad \text{(n odd)}$$
$$\sim 2^{(n-2)/2} \qquad \text{(n even)}$$

The larger n is made, the better the wanted signal can be distinguished from the unwanted ones. In other words, the longer the sequence length (N) the better. However,

$$N = T_R f_c \qquad \ldots (2)$$

where T_R = code repetition period
f_c = chip rate

and, as we have seen already, for an urban vehicle-tracking system, both T_R and f_c have practical upper limits set by the coherence time and coherence bandwidth respectively so there is a practical upper limit set on the choice of N. For the particular example quoted above we have $N \sim 5000$. With this value of N we have $n \sim 12$ and hence $R \sim 32$ giving a maximum 'process gain' of about 15 dB. Clearly in this case CDMA falls well short when its performance is compared to the available process gain (over an interference continuum) of 37 dB.

It is important to understand that the spectral components of a spread-spectrum signal are spaced by $f_R = 1/T_R = f_c/N$. For a given chip rate, long PN codes have spectral lines very close together and short PN codes have widely-separated lines. A long code may be modelled to have a continuous power spectrum but with a short code the discrete lines must be considered, particularly as they affect the process gain which varies in discrete steps according to the number of spectral lines falling into the passband of the post-correlation filter.

The usefulness of a vehicle-tracking or locating system is enhanced in proportion to the number of vehicles which can be located or tracked at the same time. A high, realisable, process gain is needed in such a spread-spectrum multi-vehicle tracking system because of the necessity of isolating each received transmission from the others; a requirement which is exacerbated by the 'near-far problem'.

From the above discussion it will be recognised that, in the frequency domain, the resulting spread-spectrum signals comprise a multiplicity of discrete spectral lines located either side of the carrier frequency and equally spaced from one another and the carrier.

The structure of the spread-spectrum signal in the frequency domain lends itself to frequency division multiplexing in a manner which makes very efficient use of the available frequency spectrum by allowing a number of spread-spectrum signals to be interleaved. This arrangement was described in the present applicant's co-pending PCT Application No. PCT/AU87/00020.

This invention exploits the quasi-discrete nature of the mobile transmitters' spectra and employs an improvement to the novel form of frequency division multiple access (FDMA) disclosed in PCT Application No. PCT/AU87/00020 to effect this isolation.

SUMMARY OF THE INVENTION

The present invention consists in a spread-spectrum transmission system wherein one or more spread-spectrum signals share a frequency band with other services, wherein the other services occupying the frequency band are arranged in discrete channels separated by guard bands, and each spread-spectrum signal has an information bandwidth which is significantly less than its spectral line or band spacing, each signal being produced by modulating a carrier with a pseudo-noise code and the spread-spectrum signal having a centre or carrier frequency and modulation frequency which are selected to cause its spectral lines or bands to occupy the guard bands separating the other service channels, the guard bands being greater than the spread spectrum information bandwidth.

In a preferred embodiment of the invention a

plurality of spread-spectrum signals occupy the frequency band and the centre or carrier frequencies of the spread-spectrum signals are spaced by an increment selected to cause the spectral lines of the respective transmitted signals to be interleaved with each other and with the channels of the other services in the band.

The invention is applicable to all spread-spectrum transmission systems where the information bandwidth is much less than the spectral line or band spacing of the transmitted spectrum. The utility of spread-spectrum systems in which the information bandwidth is essentially zero, such as systems using spread-spectrum signals for ranging purposes, is particularly enhanced.

According to other aspects of the invention, a receiver for a spread-spectrum multiplexed transmission system and a spread-spectrum vehicle tracking system are also provided.

BRIEF DESCRIPTION OF THE DRAWINGS

An embodiment of the invention will now be described, by way of example, with reference to the accompanying drawings in which:

Fig. 1 generally illustrates a vehicle tracking system in which the spread-spectrum multiplexed transmission system of the present invention might be used;

Fig. 2 graphically illustrates the frequency domain representation of a spread-spectrum signal;

Fig. 3 graphically illustrates the frequency domain representation of a spread-spectrum signal occupying the same frequency band as a conventional radio communications system;

Fig. 4 is a block diagram of a spread-spectrum transmitter for use in a vehicle tracking system using the present invention;

Fig. 5 is a block diagram of a remote site receiver

installation for use in a vehicle tracking system using the present invention; and

Fig. 6 is a block diagram of the installation of Fig. 5 showing the receiver arrangement in greater detail.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention exploits the quasi-discrete nature of the transmitters' spectra and employs an improved form of Frequency Division Multiple Access (FDMA). It was recognised in PCT Patent Application No. PCT/AU87/00020 that a novel form of FDMA could be employed with spread-spectrum signals to achieve a saving of bandwidth by interleaving spread-spectrum signals. It is now recognised that even greater efficiencies can be achieved by interleaving not only spread-spectrum signals, but also other communications channels which tend to be equally spaced across a band of the spectrum. Examples of this are broadcast radio and cellular telephone systems which generally have a number of transmitters using a number of channels which are substantially equally spaced across the band. By appropriate selection of centre and modulation frequencies of one or more spread-spectrum signals, these can be made to occupy the inter-channel guard bands of the other communications signals thereby providing a new service, in a frequency band which is already in use, without detrimental effect to the existing services in that band.

To understand the principles involved we refer to Fig. 2 which shows details of the spectrum emitted by a transmitter using a maximal PN code of length N to direct-sequence bi-phase modulate a carrier on a frequency f_o.

The diagram shows that the spectral lines are spaced by the code repetition frequency $f_R = f_c/N$ and that the spectrum of the transmitted signal is symmetrical about the carrier frequency f_o. When this signal is emitted from a mobile vehicle in an urban area it

undergoes Rayleigh scattering and Doppler frequency-shift as the radio waves propagate by a multitude of paths to the receiver. Each line in the spectrum of the received signal exhibits random frequency modulation (as described above) with most of the energy of the line being contained within a bandwidth of twice the maximum Doppler frequency-shift. Specifically, if the speed of the vehicle is v and the speed of radio propagation is c, the energy of a spectral line is contained essentially in a bandwidth $2\Delta f$ where $\Delta f = f_o v/c$. As an example, if f_o is 450 MHz and v = 100 km/hr we have $2\Delta f \sim 85$ Hz. In order to enhance the signal-to-noise ratio of this signal by processing in the receiver, the final local oscillator can be direct- sequence modulated with the same PN code as used in the transmitter, the local epoch of the code being adjusted until it matches that of the incoming code. When this happens, the energy contained in all the spectral lines of the received signal is concentrated essentially into the bandwidth 2 f centered on the final intermediate frequency. In other words, the spectrum is collapsed or 'despread' and the process gain is achieved. From the foregoing it is clear that the bandwidth of the final IF must be wide enough to accommodate the collapsed spectral energy. Allowing for an uncertainty $\pm\delta f$ in the carrier frequency of the transmitter, the final IF bandwidth should not be less than $2(\Delta f + \delta f)$.

The radiated spread-spectrum signal from each transmitter occupies a relatively wide bandwidth B (typically of the order of 1MHz). When M transmitters are operating simultaneously, as in a multi-vehicle tracking system, the use of FDMA would suggest a bandwidth requirement of at least M x B for the system as a whole. In urban areas particularly, the radio-frequency spectrum is viewed as a scarce resource much in demand. Consequently, the use of a bandwidth M x B is likely to be

considered extravagent. The present invention offers an acceptable answer to these objections without the degradation in process gain associated with CDMA.

The present invention uses the fact that although the bandwidth of the signal received from each transmitter is very wide, it has a quasi-discrete line spectrum arranged symmetrically about the carrier. If the spacing between the 'lines' is made large compared to the frequency band each one occupies and if the same spacing is used for all transmitters, it is possible to interleave these 'lines' (or bands) with conventional communications channels. Several of these spread-spectrum channels may be located in the inter-channel guard bands of the conventional communications channels by interleaving the spread-spectrum signals with each other. This is achieved by offsetting the centre frequencies of all the transmitters by relatively small amounts in the following way:

A typical, conventional, narrowband communications system will have available a multiplicity of discrete channels each of which occupies bandwidth F_{ob}, evenly-spaced within the band with separation of centre frequencies between channels of F_{cs}, where $F_{ob} < F_{cs}$. The unoccupied region between channels, or guard band, is of width F_{gb}, where $F_{ob}+F_{gb}=F_{cs}$, and serves the purpose of minimising adjacent-channel interference which may result from a combination of centre frequency errors and finite filter responses.

In the preferred embodiment of the present invention a single or multi-channel spread-spectrum system is implemented, where the band of frequencies occupied by the spread-spectrum system is shared with conventional services, but the spectral lines of the spread-spectrum signals lie within the guard bands between channels of the conventional system. Interference with the conventional

radio system channels by the spread-spectrum signals can be maintained within acceptable limits by limiting the power in the spectral lines of the spread-spectrum signals to a level comparable with that allowed from the adjacent narrowband channel. The process gain available by the use of spread-spectrum techniques can enable interference to the spread-spectrum system by the conventional system to be maintained within acceptable limits.

Let the potential number of simultaneous transmissions be M for a system comprising only spread-spectrum signal transmissions. If all of the transmitters have centre-frequency offsets which are multiples of $f_R P/M$ where P is a non-zero integer such that P and M have no common factors then the i^{th} channel has a centre frequency offset

$$f_i = (i - 1) f_R P/M \qquad \ldots (3)$$

where $\quad i = 1,2,\ldots\ldots,M$

Consider the case where this system is to occupy the same band of frequencies as a conventional radio system with parameters F_{ob}, F_{cs} and F_{gb} defined above. If parameter $f_R = F_{cs}$, and i is selected within the range

$i = 1,2\ldots Q$ where $1 \leq Q < M$ and $Qf_R/M < F_{gb}$,

then by appropriate selection of centre frequency, the spectral lines of the spread-spectrum system can be made to fall within the guard bands between adjacent channels of the conventional system. This is depicted in Fig. 3 where item 15 denotes a channel of a conventional communications system and item 16 denotes a spectral line of a spread-spectrum signal. It will be appreciated that in such a system the actual number of channels available

will be significantly less than M because of the bandwidth requirements of the narrowband communications channels.

With this hybrid spectrum usage in mind Equation 3 above can be developed as follows:

Let the selected spacing between spectral 'lines' of the composite spread-spectrum signal be f_L, the code repetition frequency be f_R and the channel spacing of the conventional communication system be F_{cs}, with a channel occupied bandwidth F_{ob}.

Firstly, we select f_R to be an integer multiple of F_{cs}; let this be R where

$$R = f_R/F_{cs} \qquad \text{(integer)} \qquad \ldots (4)$$

Typically R will be small.
Secondly, we choose the value of f_L such that

$$M = f_R/f_L \qquad \ldots (5)$$

is an integer and R is a factor of M. M represents the maximum number of spread-spectrum channels, given the code repetition frequency f_R and practical limitations on f_L, and assuming there are no communications channels with which to share the spectrum.

Now, allowing for the spectrum to be used for conventional communications channels, we define the maximum available number of spread-spectrum channels to be interleaved as Q, where

$$Q \leqslant (F_{cs} - F_{ob})R/f_L$$

therefore $$Q \leqslant M - R.F_{ob}/f_L \qquad \ldots (6)$$

Equation (6) is to be interpreted as meaning that Q is selected to be the largest integer value satisfying the

equation which also has R as a factor.

Finally, we can write the following equation defining the offsets in the spread-spectrum centre frequencies which will permit Q channels to be used. Let the offsets be f_i where

$$f_i = (i-1)\ f_R\ (K+1/M) \qquad \ldots (7)$$

(K integer)

and $i = 1,2,\ldots Q/R;\ (1+M/R),\ (2+M/R),\ \ldots\ (Q/R+M/R);$

$\ldots\ [1+(R-1)M/R];\ [2+(R-1)M/R];\ \ldots\ [(Q/R+(R-1)M/R]$

By way of illustration but not limitation, consider a typical UHF land mobile radio service overlaid by a multi-channel spread-spectrum communications system used for low data-rate telemetry and/or automatic vehicle location. The essential parameters of such a system are shown in Table 1.

TABLE 1

The parameters of one preferred embodiment are given below by way of example but not limitation.

Nominal centre frequency of spread-spectrum transmissions:	(f_o)	470 MHz
Mobile radio service channel spacing:	(F_{cs})	25 kHz
Ratio of code repetition frequency to mobile radio service channel spacing:	(R)	1
Selected 'line' spacing of composite spread-spectrum signal:	(f_L)	200 Hz
Maximum number of spread-spectrum signals:	(M)	125
Mobile radio service occupied bandwidth:	(F_{ob})	16 kHz
Available spread-spectrum channels:	(Q)	45
Frequency increments of spread-spectrum carrier frequencies:	(f_R+f_R/M)	25.2 kHz
Pseudo-noise code length:	(N)	127
Pseudo-noise code clock rate:	(f_c)	3.175 MHz

The transmitter is shown schematically in Fig. 4. A crystal-controlled oscillator and divider 21 provide a clock for the pseudo- noise code generator 22 and a reference to which the voltage-controlled radio-frequency oscillator 23 is locked via a programmable divider 24 and phase comparator 25. The output from the pseudo-noise generator is applied to the modulator 26 which bi-phase modulates (0 or π) the RF carrier. This modulated wave is amplified in the output amplifier 27 and radiated from the antenna 28.

A block diagram of the receiving electronics of a Q-channel system is shown in Fig. 5. In the preferred embodiment of an automatic vehicle location system the timing at all remote sites is synchronised to a received timing signal radiated from a fixed location. This timing transmission is received preferably by means of a high-gain antenna 31 such as a Yagi connected to the radio frequency (RF) section 32 of the timing receiver. The intermediate frequency (IF) stages of both the timing reference and main receivers are housed in the same unit 33 where the local clock is synchronised by control signals from the channel 0 timing reference receiver 37, which also supplies a reference epoch signal 50 (see Fig. 6) for distribution through this common unit to the Q main receiver channels 34.

Spread-spectrum signals from the transmitters are received by means of the vertical antenna-array 35 and main receiver RF section 36, and are converted to intermediate frequencies retaining their offsets in accordance with equation (7) above. This is effected in the IF stages. Fig. 6 shows in more detail how the Q individual transmissions are acquired and their epochs are tracked. With reference to this diagram we

note that all received spread-spectrum signals are amplified in the first wideband amplifier 41 at an intermediate frequency F. This amplifier has a bandwidth wide enough to pass all the spread-spectrum signals from the mobile transmitters. These amplified signals are split equally and passed to Q identical first mixers 42 each of which is fed by a different local oscillator 43. The frequencies of the local oscillators F_1, F_2,...F_Q are offset from each other in accordance with equation (7) just as for the transmitter carrier frequencies. Consequently receiver channel i with local oscillator frequency F_i locates the centre frequency of the signal received from transmitter i at F_o where i = 1,2,...Q. The outputs of the first mixers are amplified in second wideband amplifiers 44 and applied to second mixers 45 where the PN code generated in code generators 47 operates on the local oscillator ports. Although the same PN code is used, the epochs in each channel are independently varied in response to epoch control signals 48 produced by microcontrollers contained in the detector and microcontroller blocks 46. Each epoch is adjusted until it matches that of the incoming signal for that channel. When this occurs, the spectrum of this signal collapses to the relatively narrow band of frequencies (determined by the Doppler frequency-shift and transmitter crystal-oscillator uncertainty as discussed above) all centred on F_o. This narrowband signal appears at the output of the second mixer 45 and passes through the narrowband filter 49 to the detector and microcontroller block 46 which detects the signal and maintains a match between the incoming and locally-generated code epoch by appropriate advance/retard adjustment of the locally-generated code. There are many ways of achieving code epoch tracking which will be familiar to those skilled in the art and need not be

described here. Finally, the time difference between the epoch of the code in a tracking channel and the timing reference 50 is measured in the detector and microcontroller block 46 and the time measured for each channel is passed to the remote site computer 38 and finally via the modem 39 and land line 14 of Fig. 5 to the central computer 13 shown in Fig. 1.

CLAIMS:

1. A spread-spectrum transmission system, wherein a spread-spectrum signal shares a frequency band with a plurality of narrow band communications channels separated from each other by guard bands, said system comprising:

at least one transmitter for transmitting a signal having a plurality of spaced spectral lines or bands produced by modulating a carrier with a pseudo-noise code, such that the transmitted signal has an information bandwidth which is less than the width of each guard band and significantly less than its spectral line or band spacing, and the spread-spectrum signal having a centre or carrier frequency and modulation frequency which are selected to cause each of the spectral lines or bands of the transmitted spread-spectrum signal to occupy a respective one of the guard bands separating the narrow band communications channels.

2. The system of claim 1 wherein a plurality of spread-spectrum signals are transmitted, each having a centre or carrier frequency spaced from the others by an increment selected to cause the spectral lines of the respective transmitted signals to be interleaved with each other as well as with the plurality of narrow band communications channels in the band.

3. The system as claimed in claim 2, wherein the transmitted signal of each spread-spectrum channel has an information bandwidth of essentially zero.

4. The system as claimed in claim 2, wherein the spectral lines or bands of each of the spread-spectrum signals are spaced by a frequency f_R and the centre frequencies of the respective signals are spaced by frequency increments of $f_R(K+1/M)$ where K is an integer and M is a potential number of channels if no narrow band channels were required, M being greater than 1.

5. The system as claimed in claim 2, wherein the

selected increments by which the centre frequencies of the respective spread-spectrum signals are spaced are such that the bandwidth occupied by all transmitted spread-spectrum signals of the system as a whole is not substantially greater than the bandwidth of the individual spread-spectrum signals.

6. The system as claimed in claim 4, wherein K is chosen such that the bandwidth occupied by all transmitted signals of the system as a whole is not substantially greater than the bandwidth of the individual spread-spectrum signals.

7. The system as claimed in claim 4, wherein K is selected to be 1 and the centre frequencies of the respective signals are spaced by the frequency (f_R+f_R/M).

8. The system as claimed in claim 2, wherein each carrier consists of a band of frequencies due to the statistical uncertainty of its frequency and the spacing between spectral lines or bands of a composite signal of all transmitted signals is approximately equal to the sum of the channel information bandwidth and the statistical uncertainty bandwidth of the carriers, a code length of the pseudo-noise code and a clock rate of the code being chosen such that $f_R = Mf_L$ where M is the maximum number of potential spread-spectrum channels when there is no provision for narrow band channels, f_R is the spectral-line frequency spacing of individual spread-spectrum signals and f_L is the frequency spacing between spectral lines or bands of the composite signal.

9. A receiver for receiving a transmitted spread-spectrum signal located in a frequency band occupied by a plurality of narrow band communications channels separated by guard bands, the spread-spectrum signal comprising a plurality of spaced spectral lines or bands produced by modulating a carrier with a pseudo-noise

code, the carrier consisting of a band of frequencies due to the statistical uncertainty of its frequency, the transmitted signal having an information bandwidth which is less than the width of each guard band and is significantly less than its spectral line or band spacing, and where the centre or carrier frequency and the modulation frequency of the spread-spectrum signals are selected to cause each of the spectral lines or bands of the transmitted signal to occupy a respective one of the guard bands separating the narrow band communications channels, said receiver comprising:

receiver means for receiving a spread-spectrum transmission channel, correlation means being provided for the transmission channel to cause the spread-spectrum signal received on the channel to be collapsed to a narrow bandwidth corresponding to the transmission channel signal bandwidth which comprises the sum of the carrier frequency uncertainty bandwidth and the channel information bandwidth such that it is selected by being passed through a narrowband filter having a bandwidth corresponding to said transmission channel signal bandwidth, eliminating essentially all interference from other spread-spectrum and narrowband communications channels within the frequency band as well as wideband noise lying outside the filter bandwidth.

10. The receiver of claim 9 wherein the receiver means are arranged to receive a plurality of simultaneously transmitted spread-spectrum signals, each said signal having a centre or carrier frequency spaced from the others by an increment selected to cause the spectral lines of the respective transmitted signals to be interleaved with eachother as well as with the plurality of narrow band communications channels in the band.

11. The receiver as claimed in claim 10, wherein each channel has an information bandwidth of essentially zero.

12. The receiver as claimed in claim 10, wherein the spectral lines or bands of each of the spread-spectrum signals are spaced by a frequency f_R and the centre frequencies of the respective signals are spaced by frequency increments of $f_R(K+1/M)$ where K is an integer and M is a potential number of channels, if no narrow band channels are required, M being greater than 1.

13. The receiver as claimed in claim 10, wherein the selected increments by which the centre frequencies of the respective signals are spaced such that the bandwidth occupied by all received signals of the system as a whole is not substantially greater than the bandwidth of the individual spread-spectrum signals.

14. The receiver as claimed in claim 12, wherein K is chosen such that the bandwidth occupied by all received signals of the system as a whole is not substantially greater than the bandwidth of the individual spread-spectrum signals.

15. The receiver as claimed in claim 12, wherein K is selected to be 1 and the channel centre frequencies are spaced by the frequency (f_R+f_R/M).

16. The receiver as claimed in claim 10, wherein the spacing between spectral lines or bands of a composite signal of all received signals is approximately equal to the sum of the channel information bandwidth and an uncertainty bandwidth of the carriers, a code length of the pseudo-noise code and a clock rate of the code being chosen such that $f_R = Mf_L$ where f_L is the frequency spacing between spectral lines or bands of the composite signal, f_R is the spectral-line frequency spacing of the individual spread-spectrum signals and M is the maximum number of potential channels if no narrow band channels are present.

17. A vehicle location and tracking system, comprising:

a) a mobile radio-frequency transmitter mounted on a

vehicle to transmit a spread-spectrum signal comprising a plurality of spaced spectral lines or bands and having an information bandwidth which is significantly less than its spectral line or band spacing, the spread-spectrum signal being produced by modulating a carrier with a pseudo-noise code and the spread-spectrum signal from the transmitter occupying a frequency band which is also occupied by a plurality of narrow band communications channels separated from each other by guard bands, the spread-spectrum signal having centre and modulation frequencies selected to cause each of the spectral lines or bands of the transmitted signal to be located in a respective one of the guard bands;

b) at least three receivers positioned at known spaced locations each being arranged to receive the spread-spectrum signal transmitted by the transmitter, correlation means being included in the channel receiver to cause the spread-spectrum signal received from the transmitter to be collapsed to a narrow bandwidth corresponding to the transmitted channel signal bandwidth which comprises the sum of the carrier frequency uncertainty bandwidth and the channel information bandwidth such that it is selected by being passed through a narrowband filter, thereby eliminating essentially all interference from the transmitted signals of other spread-spectrum and narrow band communications channels within the band as well as wideband noise lying outside the filter bandwidth;

c) control means communicating with each of the receivers and including signal processing means to measure differences in the propagation time from the transmitter to each receiver and to thereby calculate

the position of the respective transmitter relative to the receivers.

18. The vehicle tracking system of claim 17, said system being arranged to track a plurality of vehicles at the same time, each vehicle being equipped with one of said mobile radio-frequency transmitters, said transmitters being arranged to transmit on different centre frequencies spaced from one another by selected frequency increments such that the spectral lines of the transmitted spread-spectrum signals interleave with one another as well as the narrow band communications channels, the receivers being multi-channel receivers and the control means being arranged to calculate the position of each vehicle carrying one of the transmitters.

19. The vehicle tracking system as claimed in claim 18, wherein the spectral lines or bands of each of the transmitted spread-spectrum signals are spaced by a frequency f_R and the centre frequencies of the respective signals are spaced by frequency increments of $f_R(K+1/M)$ where K is an integer and M is a maximum number of possible vehicles to be tracked at the same time, M being greater than one.

20. The vehicle tracking system as claimed in claim 18, wherein frequency increments, by which the centre frequencies of the respective signals are spaced, are selected such that the bandwidth occupied by all transmitted signals of the system as a whole is not substantially greater than the bandwidth of the individual transmitted spread-spectrum signals.

21. The vehicle tracking system as claimed in claim 19, wherein K is chosen such that the bandwidth occupied by all transmitted signals of the system as a whole is not substantially greater than the bandwidth of the individual transmitted spread-spectrum signals.

22. The vehicle tracking system as claimed in claim 19,

wherein K is selected to be 1 and the centre frequencies of the individual transmitted spread-spectrum signals are spaced by the frequency (f_R+f_R/M).

23. The vehicle tracking system as claimed in claim 18, wherein each of the received carrier frequencies has a statistical uncertainty which is the sum of a statistical uncertainty of the transmitted carrier frequency and a motion and/or medium-induced uncertainty in the received frequency from the mobile transmitters, and the spacing between spectral lines or bands of a composite signal of all transmitted signals is approximately equal to the carrier frequency uncertainty bandwidth due to the statistical uncertainties of the received frequencies, the pseudo-noise code having a code length and a clock-rate which are chosen such that $f_R = Mf_L$ where M is the number of channels, f_R is the spectral line frequency spacing of the individual spread-spectrum signals and f_L is the frequency spacing between spectral lines or bands of the composite signal.

24. Method of providing communication within a spectrum comprising:

transmitting a spread-spectrum signal within said spectrum, said signal comprising a plurality of frequency-spaced spectral lines or bands produced by modulating an information-bearing carrier with a pseudo-noise code such that the signal has an information bandwidth significantly less than the frequency spacing of its spectral lines or bands, wherein the spread-spectrum signal carrier and modulation frequencies are selected to locate the spectral lines of the spread-spectrum signal within respective inter-channel guard bands separating a plurality of narrow band communications channels also located within the same part of the spectrum, the guard bands being greater than the information bandwidth of the spread-spectrum signal; and

processing the received signal of said transmitted signal by correlating a received composite signal of all the signals within the band with a locally-generated pseudo-noise code to cause the spread-spectrum signal to be collapsed to a narrow bandwidth substantially corresponding to the transmitted signal information bandwidth, and passing said collapsed signal through a narrowband filter corresponding to the spread-spectrum centre frequency so as to pass only transmitted signal information and eliminate interference from other received signals as well as wideband noise lying outside the filter bandwidth.

25. A method of transmitting a spread-spectrum signal in a frequency band occupied by a plurality of narrow band communications channels separated from one another by guard bands, the method comprising the steps of:

modulating an information-bearing carrier with a pseudo-noise code to provide a plurality of frequency-spaced spectral lines or bands, such that the signal has an information bandwidth which is less than the width of each guard band and is significantly less than the frequency spacing of its spectral lines or bands; and

selecting the spread-spectrum signal carrier and modulation frequencies such that each spectral line or band of the spread-spectrum signal will occupy a respective one of the guard bands separating the narrow band communications channels.

26. The vehicle tracking system of claim 25 wherein the transmitted spread-spectrum signal has an information bandwidth of essentially zero.

27. The method of claim 25, wherein a plurality of spread-spectrum signals are transmitted, further comprising the steps of:

selecting the centre or carrier frequency of each spread-spectrum signal to be spaced from the centre

frequencies of adjacent spread-spectrum signals by an increment such as to cause the spectral lines or bands of respective transmitted signals to be interleaved with each other and with the narrow band channels.

28. The method as claimed in claim 27 further including selecting the spectral lines or bands of each of the spread-spectrum signals to be spaced by frequencies f_R, the centre frequencies of the respective signals being spaced by frequency increments of $f_R(K+1/M)$ where K is an integer and M is a maximum number of possible channels, M being greater than 1.

29. The method of claim 28 wherein each spread-spectrum signal has an information bandwidth of essentially zero.

30. The method as claimed in claim 27 further including spacing the selected increments of the centre frequencies of the respective signals such that the bandwidth occupied by all transmitted signals of the system as a whole is not substantially greater than the bandwidth of the individual spread-spectrum signals.

31. The method as claimed in claim 28 further including choosing K such that the bandwidth occupied by all transmitted signals of the system as a whole is not substantially greater than the bandwidth of the individual spread-spectrum signals.

32. The method as claimed in claim 28 further including choosing K to be 1, such that the centre frequencies of the respective spread-spectrum signals are spaced by the frequency (f_R+f_R/M).

33. The method as claimed in claim 27, further including modulating each carrier such that it consists of a band of frequencies due to the statistical uncertainty of its frequency, and the spacing between spectral lines or bands of a composite signal of all transmitted signals is approximately equal to the sum of the channel information bandwidth and the statistical uncertainty bandwidth of the

carriers, and selecting a code length of the pseudo-noise code and a clock-rate of the code being chosen such that $f_R = Mf_L$ where M is the maximum number of potential system channels, f_R is the spectral-line frequency spacing of individual spread-spectrum signals and f_L is the frequency spacing between spectral lines or bands of the composite signal.

34. The method of processing, in a spread-spectrum communication system, a spread-spectrum signal occupying a frequency band which is also occupied by a plurality of narrow band communications channels separated from one another by guard bands, each spread-spectrum signal comprising a plurality of spaced spectral lines or bands respectively located in the guard bands separating the narrow band channels, comprising the steps of:

correlating a composite signal of all the received spread-spectrum and narrow band signals with a locally generated pseudo-noise code to cause the spread-spectrum signal to be collapsed to a narrow bandwidth substantially corresponding to the transmitted signal information bandwidth; and

passing said collapsed signal through a narrowband filter corresponding to the respective channel centre frequency so as to pass only transmitted signal information and eliminate interference from other received spread-spectrum and narrow band signals as well as wideband noise lying outside the filter bandwidth.

35. The method of claim 34, wherein the communications system is a multi-channel spread-spectrum system, each of a plurality of spread-spectrum signals being frequency division multiplexed within said frequency band, wherein the respective centre and modulation frequencies are selected such that the spectral lines or bands of the individual spread-spectrum channel signals are interleaved with each other and with the narrow band channels.

36. The method as claimed in claim 35 wherein the information bandwidth of the signal is essentially zero and further selecting the narrow band filter to pass only the collapsed signal of the respective channel.

37. The method as claimed in claim 35 further including selecting the spectral lines or bands of each of the spread-spectrum signals to be spaced by a frequency f_R and the centre frequencies of the respective signals to be spaced by frequency increments of $f_R(K+1/M)$ where K is an integer and M is a maximum number of possible channels, M being greater than 1.

38. The method as claimed in claim 35 further including selecting the increments by which the centre frequencies of the respective signals are spaced, such that the bandwidth occupied by all received signals of the system as a whole is not substantially greater than the bandwidth of the individual spread-spectrum signals.

39. The method as claimed in claim 37 further including choosing K such that the bandwidth occupied by all received signals of the system as a whole is not substantially greater than the bandwidth of the individual spread-spectrum signals.

40. The method as claimed in claim 37 further including selecting K to be 1, such that the channel centre frequencies of the spread-spectrum signals are spaced by the frequency (f_R+f_R/M).

41. The method as claimed in claim 35, wherein the spacing between spectral lines or bands of a composite signal of all received signals is approximately equal to the sum of the channel information bandwidth and an uncertainty bandwidth of the carriers, a code length of the pseudo-noise code and a clock-rate of the code being chosen such that $f_R = Mf_L$ where f_L is the frequency spacing between spectral lines or bands of the composite signal, f_R is the spectral-line frequency spacing of individual spread-spectrum signals and M is the number of channels.

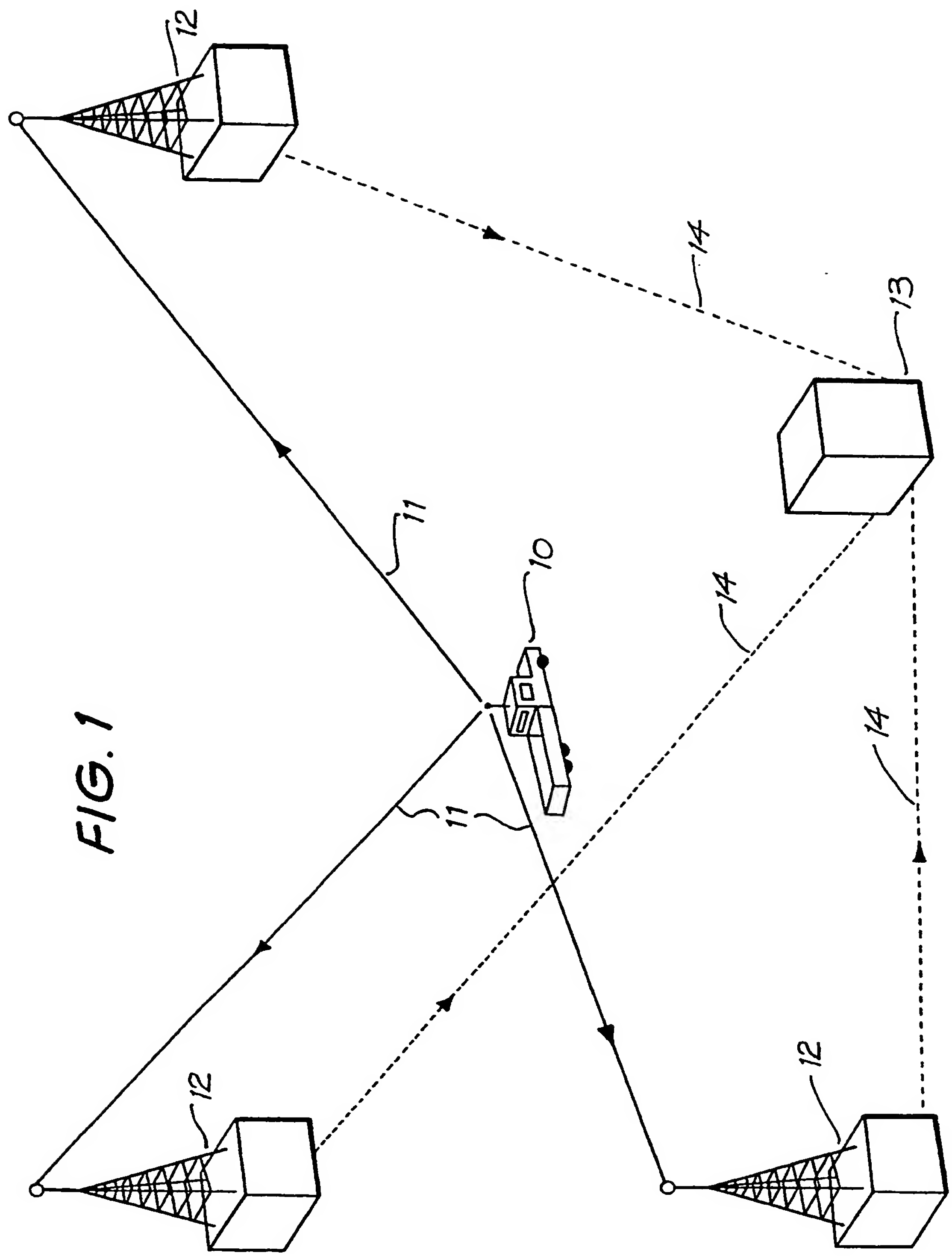


FIG. 1

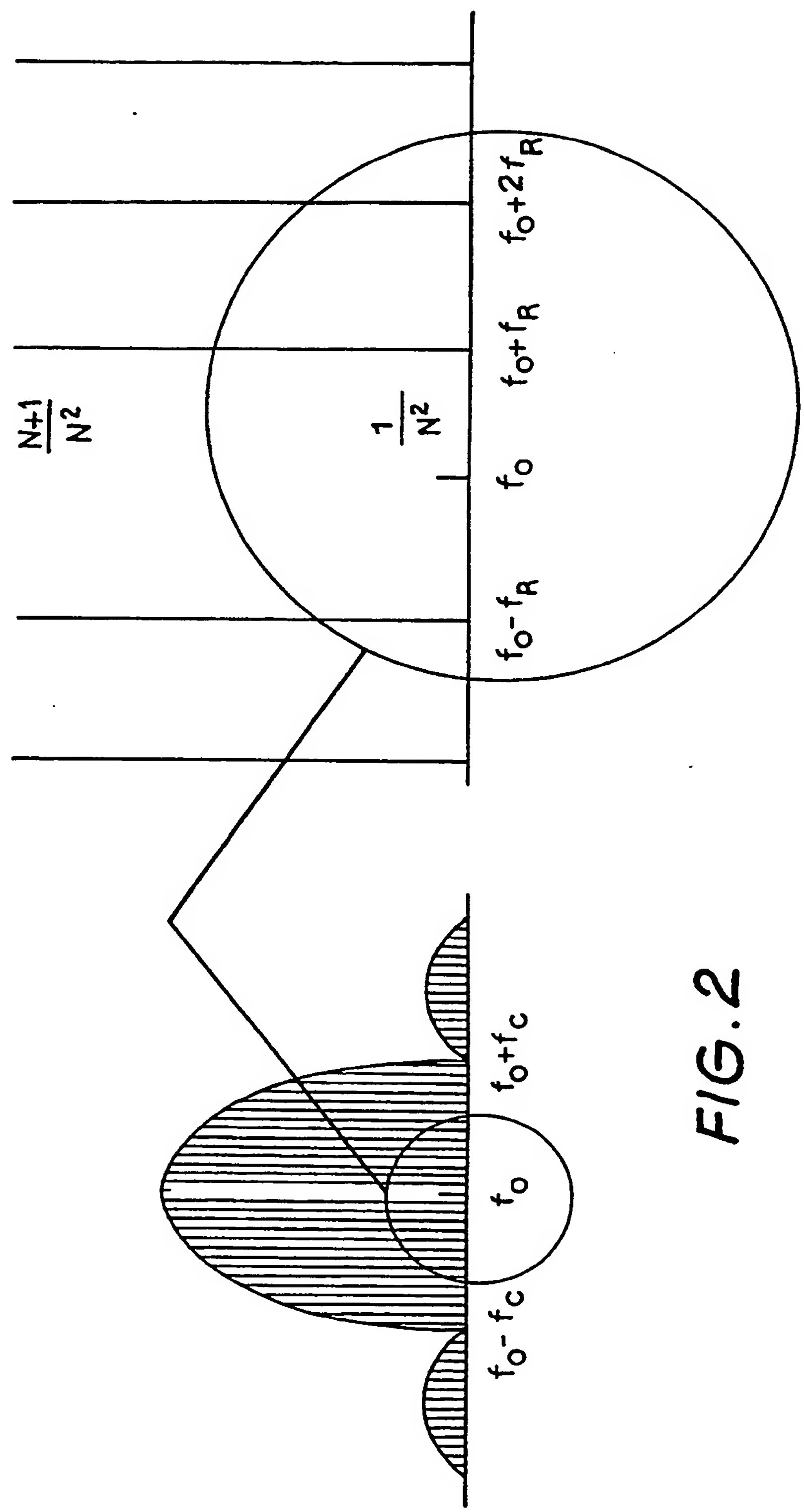


FIG. 2

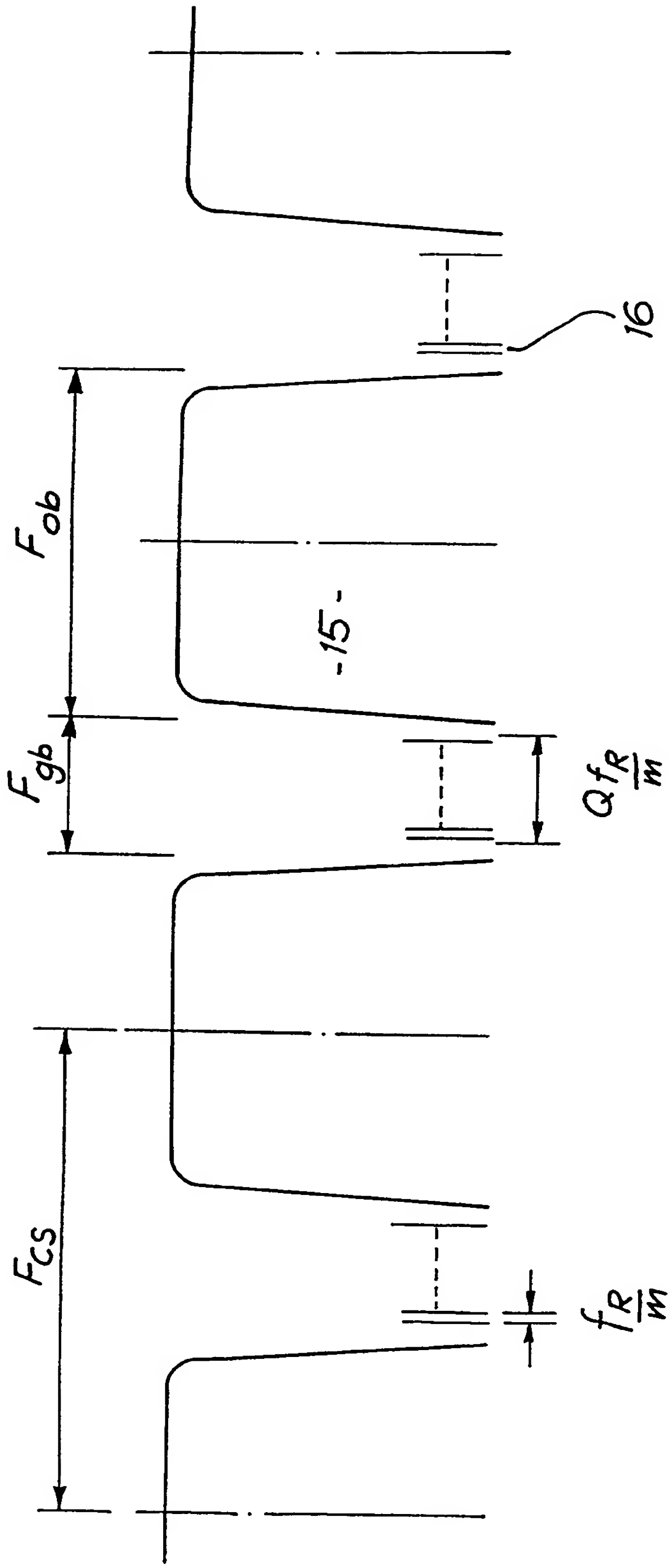
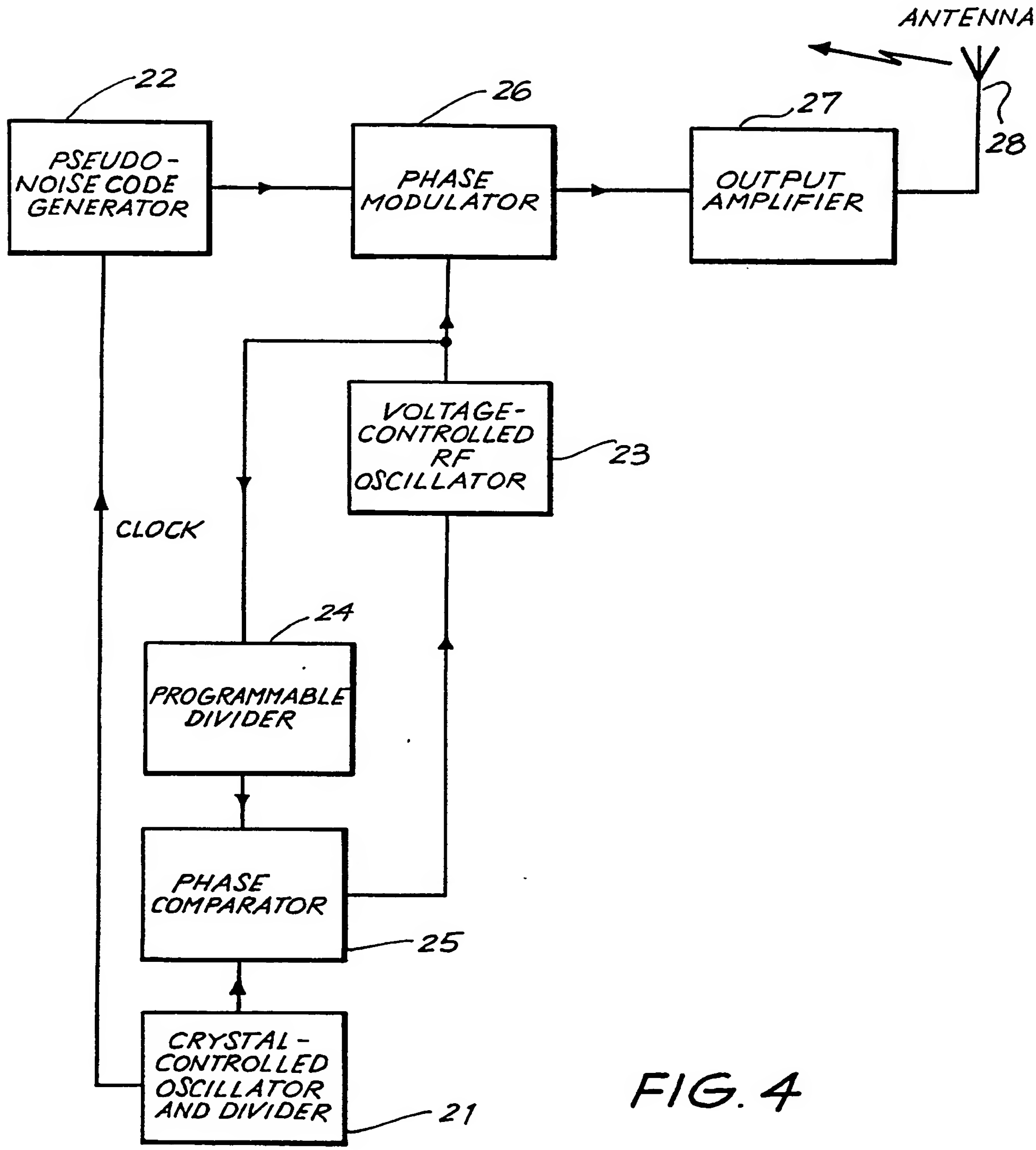


FIG. 3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22
PSEUDO-NOISE CODE GENERATOR
26
PHASE MODULATOR
27
OUTPUT AMPLIFIER
28
VOLTAGE-CONTROLLED RF OSCILLATOR
23
CLOCK
24
PROGRAMMABLE DIVIDER
PHASE COMPARATOR
25
CRYSTAL-CONTROLLED OSCILLATOR AND DIVIDER
21

FIG. 4

5/6

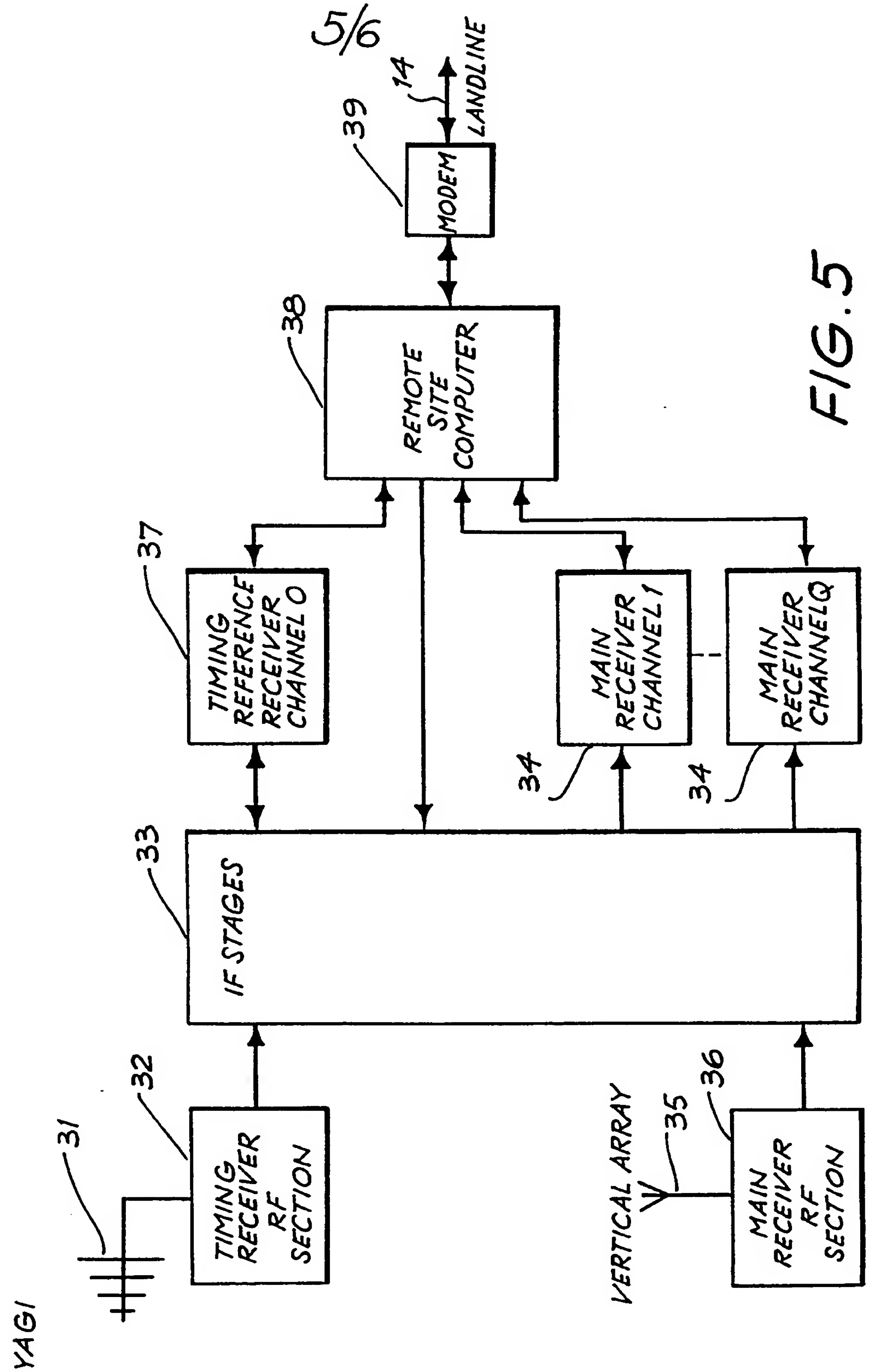
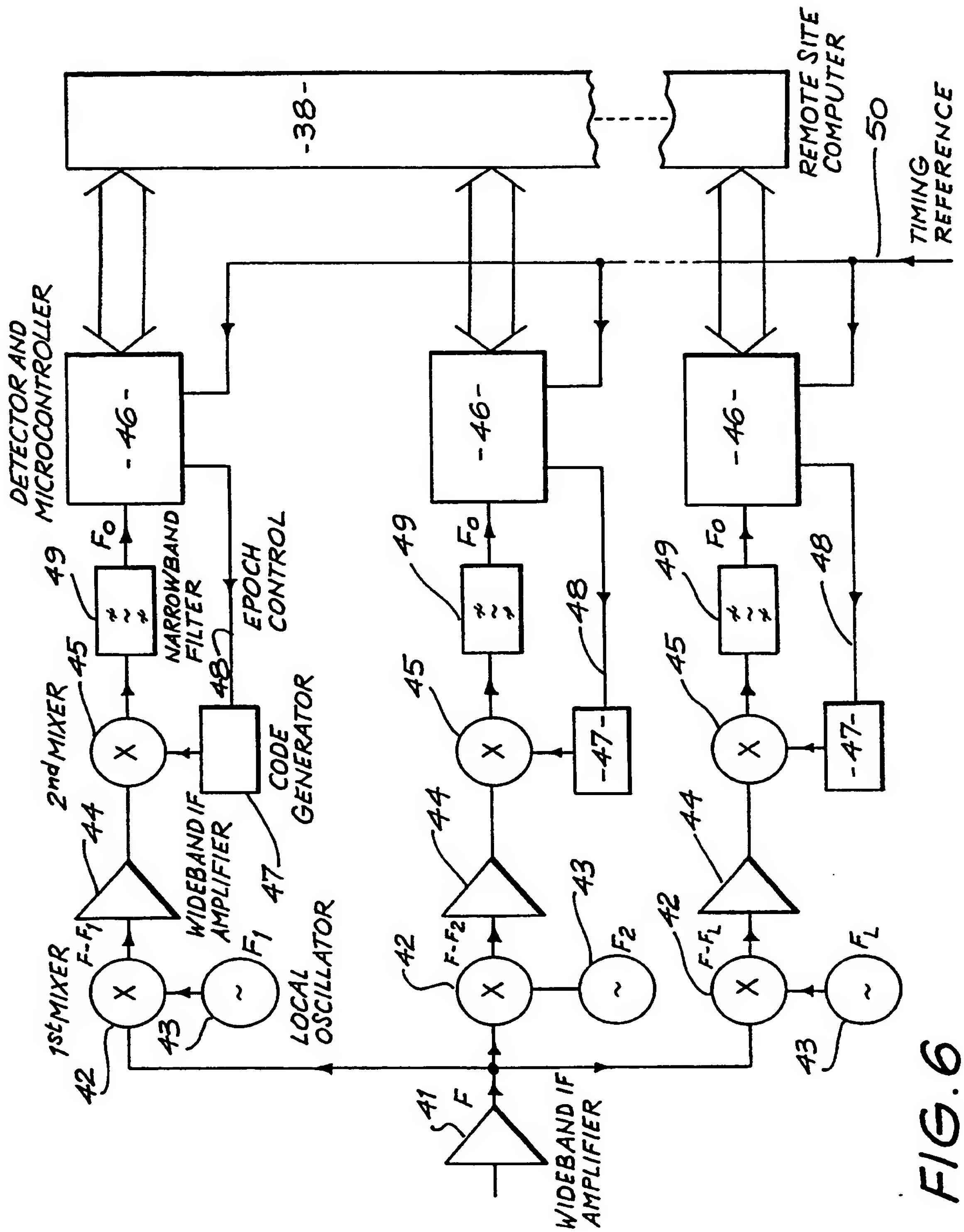

LANDLINE
14
39
MODEM
38
REMOTE SITE COMPUTER
37
TIMING REFERENCE RECEIVER CHANNEL 0
MAIN RECEIVER CHANNEL 1
MAIN RECEIVER CHANNEL Q
34
34
33
IF STAGES
32
31
TIMING RECEIVER RF SECTION
YAGI
VERTICAL ARRAY
35
36
MAIN RECEIVER RF SECTION

FIG. 5



-38-
REMOTE SITE COMPUTER
50
TIMING REFERENCE
DETECTOR AND MICROCONTROLLER
-46-
-46-
-46-
F_0
F_0
F_0
49
49
49
NARROWBAND FILTER
EPOCH CONTROL
48
48
48
2nd MIXER
45
45
45
CODE GENERATOR
-47-
-47-
47
44
44
44
WIDEBAND IF AMPLIFIER
1st MIXER
$F-F_1$
$F-F_2$
$F-F_L$
F_1
F_2
F_L
42
42
42
43
43
43
LOCAL OSCILLATOR
41
F
WIDEBAND IF AMPLIFIER

FIG.6

INTERNATIONAL SEARCH REPORT

International Application No. PCT/AU 90/00390

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) 6

According to International Patent Classification (IPC) or to both National Classification and IPC

Int. Cl.^{5} H04J 13/00, G01S 5/06

II. FIELDS SEARCHED

Minimum Documentation Searched 7

Classification System	Classification Symbols
IPC	H04J 13/00, H04K 1/00

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched 8

AU : IPC as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT 9

Category*	Citation of Document, 11 with indication, where appropriate, of the relevant passages 12	Relevant to Claim No 13
A	Patents Abstracts of Japan, E-238, page 80, JP,A, 59-2458 (HITACHI SEISAKUSHO K.K.) 9 January 1984 (09.01.84)	
A	WO,A, 87/04883 (ADVANCED SYSTEMS RESEARCH PTY LTD) 13 August 1987 (13.08.87)	
A	EP,A, 240124 (AMERICAN TELEPHONE AND TELEGRAPH CO) 7 October 1987 (07.10.87)	
A,P	EP,A, 351008 (PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LTD) 17 January 1990 (17.01.90)	
A	EP,A, 177963 (SONY CORP) 16 April 1986 (16.04.86)	
	(continued)	

* Special categories of cited documents: 10

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search 1 November 1990 (01.11.90)	Date of Mailing of this International Search Report 7 November 1990
International Searching Authority Australian Patent Office	Signature of Authorized Officer R. TOLHURST

Form PCT/ISA/210 (second sheet) (January 1985)

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

A	EP,A, 319973 (NEC CORP) 14 June 1989 (14.06.89)	
A	US,A, 4841544 (NUYTKENS) 20 June 1989 (20.06.89)	
A,P	US,A, 4912722 (CARLIN) 27 March 1990 (27.03.90)	

V. [ ] OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE 1

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1.[ ] Claim numbers ..., because they relate to subject matter not required to be searched by this Authority, namely:

2.[ ] Claim numbers , because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3.[ ] Claim numbers ..., because they are dependent claims and are not drafted in accordance with the second and third sentences of PCT Rule 6.4 (a):

VI. [ ] OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING 2

This International Searching Authority found multiple inventions in this international application as follows:

1.[ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2.[ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3.[ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

4. [ ] As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

[ ] The additional search fees were accompanied by applicant's protest.

[ ] No protest accompanied the payment of additional search fees.

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON
INTERNATIONAL APPLICATION NO. PCT/AU 90/00390

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report	Patent Family Members		
WO 8704883	AU 68940/87	EP 292487	JP 63502868
EP 240124	CA 1245292	JP 62206935	US 4703474
EP 351008	FI 893347	GB 2220824	JP 2132939
EP 319973	AU 26635/88	JP 1151843	US 4918707
EP 177963	AU 48491/85 JP 61093746	AU 588256 US 4651327	CA 1260141
US 4912722	EP 360476	JP 2116232	

END OF ANNEX